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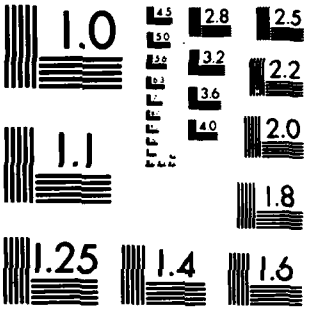

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STATISTICS AND OPERATIONS RESEARCH IN EUROPE--
1983: SUMMARY REPORT

D.R. BARR

5 January 1984

UNITED STATES OF AMERICA

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-3-84	2. GOVT ACCESSION NO. AD-A138 953	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Statistics and Operations Research in Europe--1983: Summary Report		5. TYPE OF REPORT & PERIOD COVERED Technical 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) D.R. Barr		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Office of Naval Research Branch Office London Box 39 FPO NY 09510		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 5 January 1984 13. NUMBER OF PAGES 11
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Statistics Operations research Europe

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report examines work in statistics, operations research, and closely related fields in Europe. The report updates *Statistics, Operations Research, and Management Science in Europe--1982: Summary Report*, R-2-83 (US Office of Naval Research, London, 1983).

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EXECUTIVE SUMMARY

Trends in European OR and Statistics

- European researchers hold the work of US scientists in high esteem--nevertheless there are forces at work which may generate serious language barriers in the coming years. This is already a problem in the case of France.

- There is a serious gap between the theoretical research at European universities and applications in industry. This is much more pronounced in Europe than in the US. The gap can be expected to close slowly in the next decade.

- There will be a sharp upturn in demand for operations researchers in Europe and Britain, partially because computer software for operations research (OR) is now becoming widely available. A similar but smaller impact will occur in statistics.

- OR will become more heavily used by middle management in British industry. It will be "discovered" by Scandinavian industries.

- Computing assets will continue to affect what statisticians do and how they think about problems. Special purpose statistical microcomputers ("statistical engines") will come into widespread use.

Recommendations

- Research in France should receive special attention, because of the language barrier.
- There is a great volume of high-quality research in OR and statistics in Britain and Europe. The following specific developments should be monitored:

    1. Image processing (UK, France, Scandinavia),
    2. Statistical computing (UK),
    3. Correspondence analysis and kriging (France), and
    4. Bayesian statistics applications (UK, Spain).

CONTENTS

STATISTICS AND OPERATIONS RESEARCH IN EUROPE--1983: SUMMARY REPORT

This report examines work in statistics, operations research, and closely related fields in Europe (that is, Western Europe and Israel). This report updates my *Statistics, Operations Research, and Management Science in Europe--1982: Summary Report*, R-2-83 (US Office of Naval Research, London [ONRL], 1983).

Statisticians and operations researchers in Europe generally have several characteristics in common:

- They hold work of US scientists in high esteem;
- They write professionally in the English language and use English to overcome the language barrier (except for French researchers);
- They have US ties and contacts (most have visited the US as students or on sabbaticals, or at least for conferences); and
- They like to publish in US journals.

This means that a great proportion of the research of European scientists eventually becomes accessible to their US counterparts (with a several-year lag for the publication process). This US (or at least English-speaking) orientation of European scientists is of tremendous value to the US, and it would be prudent for us to take active steps to encourage this to continue.

There is considerable danger that there will soon be an end to one of the major sources of US-oriented European academic scientists--Europeans doing graduate studies in US universities. There are two reasons for this: more and more alternatives are available for graduate studies outside the US, and, more important, European universities are not recruiting new faculty members. The latter has occurred as a result of growth in the 1960s, which led to building over-capacities in many, if not most, European universities. The typical situation is a department with a group of middle-aged faculty, growing older together, with decades until retirement, and with little prospect for significant recruiting of newly educated young faculty. In the recommendations at the end of this report I reiterate the need for significant US funding to encourage and assist exchanges of "mature" faculty researchers between US and European universities and research centers.

Another, perhaps relatively minor, factor relating to use of English as a standard for research reporting is the high cost of US monographs and textbooks in most European countries. According to publishing representatives and editors I have talked to, a major factor in the high prices charged for textbooks in Europe (usually at least twice their US prices) is the local bookstore's markup. Apparently, in many countries books must be retailed by bookstores only. Although I don't see an easy solution to this, it is unfortunate that these English-language materials are in effect not available to many potential European users. One offshoot of this is the growing practice of preparation of reading materials for students by faculty, in the local language. A similar trend seems to be occurring in computer software.

These comments relating to the language barrier lead naturally to the next section, which discusses the only European country in which this problem is already serious: France. Following that are sections commenting on work in Germany, Scandinavia, and the UK. In these sections, I have attempted to discuss research that is unusual (by US standards) or that represents noteworthy trends. I have included a section related to computers, in order to support my thesis that the coming widespread use of OR and statistical computing assets will generate important changes in these fields in Europe in the coming decade.

France

In ONRL report R-2-83 it is noted that because of the language barrier,

work in France tends to be relatively slow to become widely known outside the country. Statistics and OR work in France tends to be of two quite distinct types: the very theoretical (mathematical) work done by faculty in university departments, and the applied work done by engineers and others under labels other than statistics and OR. Two areas, which were mentioned in R-2-83, have emerged from the applications people: correspondence analysis and kriging.

Recently, English-language monographs and journal articles on these methods have been published, so perhaps lengthy comment on them is not appropriate here.

There is, in fact, some rather old English-language literature related to correspondence analysis, going back to Hirschfield (1935) and Fisher (1940). These early works are described in an article by M.O. Hill, "Correspondence Analysis: A Neglected Multivariate Method," *Applied Statistics*, Vol 23, No. 3 (1974). There is apparently an extensive French literature on the subject; the leading French researcher on basic theory in this area is Prof. J.P. Benzécri (who coined the term "correspondence analysis") at L'Université Pierre et Marie Curie (Paris VI); leading applied research is being done by Yves Escoufier and his colleagues at the Centre de Recherche en Informatique et Gestion, Montpellier, France. Fortunately, a book on correspondence analysis, in English, is due to appear very shortly. Prof. Michael Greenacre (Department of Statistics, University of South Africa, Pretoria) is the author, and it is being published by Oxford University Press. A paper by B.F. Schriever (Mathematisch Centrum, Amsterdam), "Scaling of Order Dependent Categorical Variables With Correspondence Analysis," has just appeared in the *International Statistical Review*, which gives an excellent review of correspondence analysis and cites several further references.

The second area with very strong French involvement is kriging. There are groups in the US working in this area as well--I have been told that one of the most active is at the University of Kansas, Lawrence, in the Kansas Geologic Survey group headed by John Davis. There is also a recent book on the subject by Isabel Clark (Geostakos Ltd., 80 Lower Grosvenor Place, London SW1W DEN). At the International Statistical Institute meetings in Madrid, Pierre Delfiner (Études et Productions Schlumberger, France) reviewed some of his recent work on kriging.

Thus, the pioneering French work in both correspondence analysis and kriging is just now becoming widely available in the English language, after a significant (and serious) delay. Transfer of US and British methods into France has also been slow in some cases. For example, even though there has been a segment of the scientific community in France active in data analysis and innovations such as graphical methods, "Anglo-Saxon methods" (as they are described by one leading French statistician)--such as robust methods, jackknife statistics, and the bootstrap--are just now being imported into France.

In summary, French statistics and OR seem to be conducted by two distinct groups. One is the university faculty, who do very good theoretical and mathematical work--often to the exclusion of real applications, and often without concern about, or access to, actual data. This is true even in traditionally applied statistics areas such as economics and decision aiding. The other group is concerned with applications in France and tends to be made up of engineers and individuals working in industry. Graduate students are tending to get more involved in applications in areas of current social concern, such as pollution, medicine, and agriculture. A significant point is that these two groups are essentially disjoint and generally do not communicate with each other. Perhaps the most significant point is that the language barrier is indeed slowing transfer of science and technology in both directions between the US and France.

Germany

West Germany (the Federal Republic of Germany [FRG]) competes with France as the European country which is most committed to R&D. In 1980, for example, nearly $18.5 billion was spent on R&D, of which about 60 percent came from federal sources. The FRG has high labor costs and few raw materials and energy resources, so it must depend on its diffuse R&D system--consisting of universities, industries, nonprofit private institutes and societies, and federal and state research agencies--to generate technical innovations which will allow her to maintain export competitiveness. This dependence of the country's well being on technical competence and leadership has forced Germany to spend more on R&D than any other country in Western Europe. Per capita spending on R&D is about twice that in Britain, for example, and (excluding defense research) is more than that in the US for government and industry combined. Significantly, FRG Ministry of Defense expenditures for defense R&D peaked in 1979 (at about $700 million) and dropped by nearly 20 percent in 1980 (to about $570 million).

Despite the heavy funding for scientific R&D in the FRG, there are some problems. Many Germans think there is a crisis in German research and that there is not enough output for the level of funding input, particularly when compared with the situation in the US. This lack may be due in part to the tremendous growth of research establishments, especially the universities, in the past 20 years; part of the problem may also be due to lack of a good measure of R&D output. As in France, there is a trend toward more emphasis on research related to social problems such as ecology, nuclear power and other energy systems, and health and safety. As mentioned above, there is a rather sharp trend away from funding for defense research. There is a general trend in statistics and OR in Germany toward applications, judging from graduate student research projects.

Operations research as an entity is not big in Germany. There is significant OR-related work in many industries and a few universities. For example, the Industrieanlagen-Betriebsgesellschaft-IABG research facility near Munich has some good research in OR, with applications to military and governmental problems. There are very few chairs in OR in the FRG. One, held by Prof. H. Muller-Merbach (currently president of the International Federation of Operations Research Societies), has just recently moved from the University at Darmstadt to one of the "new universities" at Kaiserslautern. Muller-Merbach and his associates are working on problems of the OR process, its organization, approaches, and philosophy. He is currently working on an empirical study of OR and systems-analysis (SA) problems and practices, and in particular how software development and use evolves in organizations. "I think OR activities should be close to data processing," Muller-Merbach recently told me.

A second center of OR in Germany is the Technical University in Aachen; the chair is held by Prof. H. Zimmermann. There are 35 faculty and associates (PhD students) in this chair, with specialities in psychology, mathematics, engineering, computer science, and statistics. The institute headed by Zimmermann has the only master's degree program in OR in the FRG. This program is strictly graduate, and students entering it must have master's degrees in mathematics, engineering, or economics. Zimmermann is well known for his work in the area of fuzzy sets and their applications to linear programming (LP) problems. He has recently developed a decision-aiding system based on fuzzy LPs, under contract with the US Army.

Human factors research in the FRG is classified under experimental psychology. There has been a significant shift from clinical psychology toward experimental psychology in the past decade, but even so the level of activity in human factors seems relatively lower than in the US. Again the majority of the work is theoretical,

without endorsement and application by potential users.

There is some very good military OR research in Germany. I have already mentioned the work at IABG; also near Munich is the Hochschule der Bundeswehr München, a university for the German armed forces. A department there, headed by Prof. R. Huber, is engaged in a wide variety of OR and SA research, ranging from arms-limitation negotiation and force balance to combat modeling. Huber is well known for his work on hierarchical models of combat. This approach to combat modeling is different from the most common one used in the US. In the hierarchical approach, various levels of combat are modeled separately, with outputs from each level determining the inputs to the next level. According to Huber, this allows more realism to be played, with a limited number of options, at the higher levels. Huber is active in the North Atlantic Treaty Organization (NATO) working group dealing with operations research, which seems to devote itself to studying "issues" rather than developing basic research.

There are few statistics programs as such in German universities; statistics chairs are usually in mathematics departments. Most of the statistics research in these groups is quite theoretical, and there seems to be a gap between university research and applications in government and industry. The mix of research areas seems to be about the same as in the US; possibly more emphasis is being placed on extreme values and applications in "insurance mathematics." Some chairs are being created in insurance mathematics, and many universities have courses in this area. Two leading researchers in extreme value theory are Prof. J. Teugles (at Katholique University, Louvain, Belgium) and Prof. F. Rauhut at Aachen Technical University.

There is also a lot of activity in quality control, although a few of the German statisticians I visited remarked that they think this is beginning to wind down. There is a very active quality-control group at the Free University of Berlin; members of this group are coordinating their efforts with other European quality-control researchers, including groups headed by P. Tyregod (Technical University of Denmark, Lingby), B. Wetherill (University of Kent at Canterbury, UK), and I.G. Evans (University College of Wales, Aberystwyth).

In summary, there is significant research in statistics and OR, much of it classified under mathematics or engineering, in German universities. The university work tends to the theoretical, and there is a gap between that work and the applications. There is a trend toward more awareness of applications among current graduate students, probably because of the labor market in Germany; there is virtually no chance for new graduates to gain permanent faculty positions.

Scandinavia

It may be inappropriate to group the statistics and OR research in Denmark, Norway, Sweden, and Finland into one category, because there are significant differences among them. But there are also points of similarity, and, rightly or wrongly, many of us do tend to think of these countries as a single unit. There is very close cooperation among the Scandinavian countries, and citizens from any one of them may travel to the others without visas or work permits. Indeed, once travellers from abroad enter any of these countries, they may pass freely without even a passport check at the borders.

Perhaps Norway can be used as an example. In terms of population, Norway, with just over 4 million inhabitants, is a small country. Total R&D expenditure in Norway is just under $500 million per year, which is roughly 1.5 percent of her gross domestic product. About half of the total R&D spending is in the business sector. A little over half is government funding, of which about half goes to institutions of higher education. Government R&D is

administered by a research-council system in which councils are attached to various ministries, such as Education, Industry, Agriculture, and Fisheries. The 40-member Norwegian Council for Scientific and Industrial Research (NTNF), for example, is attached to the Ministry of Industry, although it has members representing other ministries as well as various industries and research institutions. The NTNF directly sponsors research in fields such as manufacturing, construction, and shipping; it has also established over a dozen research institutes and is directly involved in international research cooperation--such as space research in collaboration with the European Space Agency and the US National Aeronautics and Space Administration.

A major portion of the basic research in Norway is conducted in her four universities (at Oslo, Bergen, Trondheim, and Tromsø) and several colleges. Norway also has several applied research institutes, most of which were originally established by the NTNF. Though funded by the various ministries, these institutes are essentially self-governing. The Norwegian Computing Center (NCC) is an example of such an institute which is carrying out significant OR and statistics-related research.

There is a moderate level of OR research in Scandinavia, almost all being done in small groups in universities. However, outside the defense laboratories, there are virtually no applications in industry. In all four countries there are fairly active operations research societies, which encourage cooperation on research related to regional problems. For example, the Finnish Operations Research Society recently hosted the first "Nordic Operations Analysis Seminar on OR in the Forest Industry." The organizers scheduled a wide variety of papers related to forest-industry applications such as analyzing timber stocks and demands, providing computerized production control in paper mills, and using mathematical programming to optimize forest-felling yields for sawmill demands. I was told by several university researchers that there is virtually no one in Scandinavian industry called an operations researcher. A common question was, "How can we get operations research accepted by industries?" (I will return to this issue below.)

There is a very good management science (MS) group at Odense University in Denmark. This department is unique in Scandinavia in that it has taken a very quantitative point of view, concentrating in selected areas such as marketing and organization theory. The head of this group, Børge Obel, has done pioneering work in applying OR methods to organizational design theory. His work involving the use of organization simulation, in collaboration with Prof. R. Burton of Duke University (US), is especially noteworthy. He is now turning to experiments with organization structures using gaming, with people taking part in nodes of the structure. One of his goals is to investigate the nature, role, and effects of reward structures in organizations. The Odense group is cosmopolitan, with members who have received PhDs from universities in various countries (including the US).

Statistics in Scandinavian universities is, with one or two exceptions, quite theoretical, as in France and Germany. The most glaring exception to this is the Institute of Mathematical Statistics and Operations Research (IMSOR) at the Technical University of Denmark, Lingby. This department has about 20 members, with about 15 associates (PhD students) working on a variety of significant applications. Head of the institute is Prof. P. Thyregod, who is active in quality control. Most important areas of OR are represented in the department, and current work includes teletraffic theory, control theory, technology assessment, location and routing, tide- and surge-level prediction, and time series models.

Like OR, statistics has been rather slow to be embraced by Scandinavian industry. There are some beginnings--for example, a small group at the Volvo

Data Division in Göteborg, Sweden, will, I think, mature into an important statistics group within a few years. There is quite an active group of statisticians at the NCC. But it is remarkable that so few operations researchers and statisticians are to be found in most industrial settings. A good example of this is the Norsk Hydro facility in Porsgrunn, south of Oslo. Norsk Hydro is the largest private industrial concern in Norway. Its major product is fertilizer (based on nitrogen production), but it also has interests in petroleum-related products such as plastics, and in metals, such as magnesium extracted from sea water. (As an aside, it is interesting that these products, many of which consume large amounts of electric power in their manufacture, take advantage of Norway's cheap hydroelectric power supplies. For example, bauxite is imported from Jamaica and transformed to aluminum in Norway. I was told it costs about $100 to heat the average Norwegian home in a winter month by electric power; the cost with coal or oil would be much higher.)

The Porsgrunn facility of Norsk Hydro employs about 5000 workers and has a research department with about 300 professionals (mostly chemists and chemical engineers), and one statistician, Nils Standal. Standal's work is mainly concerned with pollution studies. Work on quality control, safety, experimental design, and modeling of chemical processes is apparently carried out, at a low level, by engineers and chemists. Standal told me that in a study he made of the employment of 60 recent graduates from Norway's statistics programs only *one* has gone into industry.

Norsk Hydro is interesting also with respect to its use of computing resources. For historical reasons, the company has a number of mainframe computers and minicomputers of various makes and models in its facilities all over Norway. It is now acquiring fairly large numbers of microcomputers, again of various kinds. The system has been networked into a laboratory-data system, using switchboards under the control of the RS/1+ system developed by Bolt Beranek and Newman Inc. in the US. All of Norsk Hydro's laboratories are hooked into this lab-data system. Experiments in individual labs are generally controlled by microcomputers, which are programmed for automatic data capture, analysis of lab data, and (with word-processing software) report writing. Linkage to the lab-data system facilitates interaction by various scientists, monitoring of experiments by management, and record keeping. For example, the lab journal in each laboratory is maintained in each laboratory's microcomputer, with archiving in the lab-data system.

Microcomputers are just now becoming common in Scandinavia, and there is a fair amount of software-development activity, particularly with respect to statistical packages. One particularly interesting package is SURVO76, developed by Prof. S. Mustonen at the University of Helsinki. This package, running on Wang minicomputers and microcomputers, is a very impressive system which provides support for database generation and management, statistical and mathematical data processing, graphics, text processing, and report generation. (Mustonen also showed me output from software he developed to generate camera-ready music scores. His motivation for this was to assist his son, Oli, who is already, at age 16, a well-known musician and composer.)

A second noteworthy Finnish statistical software package is the KONSTA system developed by S. Puntanen and T. Pukkila at the University of Tampere. This is an interactive system designed primarily for use in teaching statistics. It is used at Tampere primarily by students taking their first statistics courses. The system must therefore be extremely user friendly and robust, and must allow easy entry of data as well as access to stored data sets. One interesting feature, with which I had an opportunity to get some experience, was a matrix-computation program. Using this program, the student can easily write regression programs in "natural"

language, for example. KONSTA is written in Fortran and runs at Tampere on a DEC 2060 with about 100 time-sharing terminals. There is also interesting work in the department at Tampere on time-series modeling, particularly multivariate Box-Jenkins models, and on linear models, particularly concerning estimability and testability.

A third software effort that should be mentioned is the OPUS program developed by Systecon AB in Stockholm. This program is designed for optimization of spare components (types and numbers of spares and where spares should be located) for large systems. The program can handle systems with up to 40,000 components in eight echelons with systems of rather general structure. It can be used for initial procurement and allocation problems, as well as for analyses of current allocations and replenishment procedures. Hans Ebenfelt, president of Systecon, told me, "There is a growing trend for sponsors to set operational specifications for systems, requiring contract proposers to show how their systems will meet these specifications." The OPUS program can be useful in determining the operational availability a system can achieve with various funding levels, for example.

In summary, there is good statistics research in Scandinavian universities, with some significant applications occurring in government labs, such as the NCC. Software packages being developed for statistical and OR applications are beginning to be available and will probably bring these methods into much greater use in Scandinavian industries. Interestingly, there is very little interaction with Soviet scientists--even in Finland, which presumably has relatively easy access to the USSR. As with the other European countries, Scandinavian scientists generally align themselves with the West, and with the US in particular.

The United Kingdom

OR in the UK is something of a paradox. In ONRL report R-2-83, I mentioned that OR research in the UK tends to be more applied than that in the US. Indeed, operations researchers in the UK tend to be critical of much of the work published in US OR journals, believing that it is too theoretical and is driven by the publish-or-perish pressures in US academic departments. I think this view has some validity, but there is another interesting side to OR in the UK which is not so obvious. This is related to the "crisis in OR" that is mentioned so often in Europe.

Let me cite a couple of examples to introduce this "hidden" side of the UK's "OR situation." In discussions of it, British authors frequently use arguments along the following lines:

"Operational research (as OR is called here) is concerned with what happens in organizations, and, because this involves people, it must therefore deal with psychology and social science. This means OR must swing back from highly specialized studies and techniques toward *less* sophisticated attention to the various aspects of practical problems. This swing must encompass renewed interest in the social sciences."

My second example concerns conclusions about education in systems science (OR), stated by a NATO study panel a few years ago, which I think represents a view held by many British operations researchers: "The development of mathematical theories for systems science has, for the most part, advanced far beyond the requirements of real-world practice, and educational programs give too much emphasis to the mathematical aspects of systems science." The report goes on to suggest an increase in "an understanding of individual, group and organizational behavior...." This sentiment has been echoed by many of the British OR people I have met.

Now the apparent "paradox" I alluded to is this: if British OR is, to a certain extent, contemptuous of the theoretical orientation of published US OR, why does one hear so much in Britain about the need for the "swing into

social science and psychology"? Has not British OR already swung there? Is it not already much more applied than in the US? I think the answer is that even though British OR *publications* tend to discuss case studies and practical experiences (in contrast to US OR publications), it is dangerous to conclude that British industry applies OR methods more than do US industries. In fact, it appears that the opposite is true. As H. Muller-Merbach observed in one of his IFORS newsletters:

"American industry already employs in its normal middle ranges of management men used to some of the approaches and techniques that in Britain have been left to the operational researchers to disclose to the industrial ken. It is certainly true that American industry has a far greater competence in using statistical methods ... deciding the most profitable way to operate its business. Economists, for example, exist there far beyond the confines of the information and forecasting department to which they are now being admitted in British industry, as practising technicians...."

It appears that British industry and management have not in general taken advantage of OR techniques to the extent that their US counterparts have--the excellent OR departments in the nationalized industries such as the National Coal Board notwithstanding. Why have middle managers been slow to adopt OR methods? The following seem to be some of the reasons:

- The gain that can be achieved by use of optimization (over current management practices) is often only on the order of 1 percent. Of course this can be a substantial amount of money--for example, the Central Electricity Authority spends about $50 million each year to move coal from about 800 mines to roughly 200 power stations in Britain. Thus, by optimal choice of coal allocations and methods of transport and routing, for example, a large saving is possible, even though the relative amount is small. Still, many managers think optimization is "not worth the effort."
- It is generally perceived by people outside British OR that operations researchers don't (can't?) help with everyday, real-life problems;
- British OR people don't communicate well with managers;
- British operations researchers are not "exposed" as managers are; and
- British OR educational programs teach their students the wrong mix of skills, with not enough emphasis on the actual, overall, interactive problem-solving process.

I think the plea for more training on how organizations operate and for more awareness of sociology and psychology among British operations researchers is really designed to provide easier entry of British OR types into British industries. There is, I think, a great potential in the UK for more interaction of operations researchers and middle management of a wide variety of firms and industrial concerns. Partly because of the growing use of OR software in these institutions, awareness of this need will continue to increase. This may well lead to rather sharp growth of operations research in Britain in the next 5 to 10 years.

Of course, there is excellent OR work ongoing in the UK. The OR department at the University of Warwick and the Management Science Institute at Manchester University are examples of groups having strong research programs in OR. There is also a lot of excellent OR research being conducted at government organizations such as the National Coal Board, British Telecom, British Rail, and British Airways. Some work is also being done in defense-related organizations, such as the Royal Military College at Schrivenham.

Statistics education in the UK is interesting because there seems to be a trend toward incorporating statistics into undergraduate curricula (usually of math majors) and dropping master's

degree programs in statistics. For example, the statistics department at Birmingham, with a number of excellent faculty actively doing statistical research, has recently terminated its master's degree program in statistics. The reason for this seems to be a lack of students choosing to do MS work in statistics, which in turn reflects the current employment situation for statistics graduates. Unlike in the US, where the statistics area apparently held up relatively well during the recent recession, the impact in the UK has been quite pronounced. "All the bright young maths students are going into information technology," I was told on several visits to UK universities. I do not think this a permanent trend, however; statistics in the UK will enjoy growth similar to that coming in OR, for similar reasons.

Statistics research in Britain is generally the same as in the US. There is a great deal of high-quality statistical work being done in British universities, both of an applied nature and in mathematical statistics and probability theory. Listed below are some, but certainly not all, of the outstanding groups in statistics (in no particular order). The statistics department at Birmingham University is headed by John Copas, who is doing some exciting work on regression. The statistical computing group at Rothamsted Experiment Station is headed by John Nelder, who is doing important work on linear models; also at Rothamsted is Rosemary Bailey who, with H.D. Patterson at the University of Edinburgh, is doing some very interesting work on "design keys" for experimental design. The group at the University of Kent at Canterbury, headed by Barry Wetherill, is turning out good work on a variety of applications, including Wetherill's research on quality control; this group is also developing impressive statistical software for microcomputers. Of course the University of London's campuses are centers of statistical research. D.R. Cox's department at Imperial College is outstanding. Perhaps the brightest new star in the system is Phil Dawid at University College. He and his colleagues are attracting some of the best graduate students in Britain, and the work being done in foundations of probability and statistics--particularly in Bayesian statistics--is of very high caliber. It seems clear that Dawid will emerge as one of the top statistical thinkers of our era.

In summary, there is a large volume of good research in OR and statistics in the UK. There are some temporary difficulties due to the economic situation in Britain, which has hit universities particularly hard, and due to current fashions in a tough employment market. But the longer term outlook for both OR and statistics is very good, with OR facing a possible sharp upturn in the coming decade. One of the major catalysts in this resurgence is the computer; the availability of good, inexpensive software and hardware will lead to its widespread use, which will in turn generate demand for OR and statistical professionals.

Computing

ONRL report R-2-83 describes the widespread software-development efforts by university and industry scientists. This work ranges from development of major packages to run on mainframes (such as the GLIM and GENSTAT packages) to a wide variety of software products for microcomputers (such as the statistics and quality-control programs developed at the University of Kent at Canterbury). Virtually every department I visited had some form of software-development activity, and in many departments it is a major activity. It is clear that computing assets (hardware and software) are becoming universally available to scientists, managers, and technicians throughout Europe. Let us examine some probable effects of this "revolution."

One effect will be on the nature of the research in OR and statistics, both in terms of what is done (the problems considered) and how it is done. For example, automatic microcomputer-

controlled capture of data from laboratory experiments and real-time monitoring functions (such as stresses in aircraft wings) is going to generate very large data sets, requiring special statistical methods. As another example, we are already seeing a significant resurgence of interest in graphical methods, undoubtedly brought on by the availability of computer graphics. Also, much of the data-analysis technology was infeasible before widespread availability of computing resources. Obviously, similar comments can be made about expert systems and robotics, image processing, mapping techniques, and various other applications for artificial intelligence.

So the first point is that the natures of what operations researchers or statisticians do and, significantly, of how they think about problems are undergoing rapid transition because of availability of computing resources. The second point I want to reiterate is somewhat economic in nature. The lack of OR (and to a lesser extent, statistics) applications in many European industrial concerns (especially in Scandinavia) seems a strange contrast to both the need for these techniques and their availability. It is likely that industrial concerns will acquire statistical and OR software, and inevitably this will lead to "discovery" of the usefulness of these disciplines. It is also probable that such applications will lead to an appreciation of the need for professional services in these areas. Thus, we can predict a very substantial increase in interest and activity in the OR and statistical applications areas throughout Europe. This can also be expected for OR in Britain.

Part of the "discovery" will come as firms learn proper uses for their microcomputers. Currently, many firms are restricting their microcomputers to management and bookkeeping tasks (such as payroll applications). In many contexts, microcomputers are better used for "local" control, planning, and decision aiding. A good example of the latter is the Visual Adaptive Simulation in use at British Leyland. Similarly, there is immense impact on what can be done on the local level. For example, quality-control applications can have nearly automatic processing of quality data, without visible "plans" and "tables" for implementing quality management.

Finally, I shall comment briefly on computer-aided instruction (CAI). Generally, there is great excitement, among a relatively small group of adherents, about CAI in Europe. There is a great deal of sales resistance among the rank-and-file university community concerning the adoption of current CAI products. Some think CAI is just a fad that will disappear in a few years. It must be agreed that, historically, innovations in education have been few and far between, and that the "prior" on CAI success may therefore be low. Probably the disenchantment of some educators about CAI is due to early problems with unreliable hardware and poor software. My impression is that current CAI efforts are achieving only moderate success here, as measured by popularity and numbers of adoptions. However, a growing number of workers are developing CAI materials, and it certainly shouldn't be written off. The use of OR and statistical software packages in connection with classes in these areas (and in related engineering, biology, and economics classes) is, of course, very widespread. Interestingly, the GLIM package is widely used--in contrast with the US, where other packages dominate. I think GLIM and GENSTAT should come into wider use in the US; they are excellent, unique, and inexpensive.

Conclusions

In the previous section, I tried to make clear that the increasing availability of computing resources is having, and will continue to have, a very important impact on statistics and OR in Europe and Britain. It appears that substantial new demand for operations researchers and statisticians will

result. New directions for research in these areas will surely also continue to be affected by computing.

There is something of a "gap" between university research and industrial applications. This charge is also often made about the US, but the effect is not nearly as pronounced as it is in Britain and Europe. One reason for this is the full-year contract held by each European faculty member, and thus the lack of need for "research contracts" for supplemental work to cover the summer break as in the US. Another is the relaxed attitude of most European faculty; generally there is not an atmosphere of "hustling" to exploit ideas and inventions in coordination with industry, as in the US. Very few of the faculty members I visited were engaged in consulting activities, for example. This gap is slowly closing, however, because of the changing employment situation in Europe--new university positions are virtually nonexistent, so graduate students are tending to prepare themselves to go into industry.

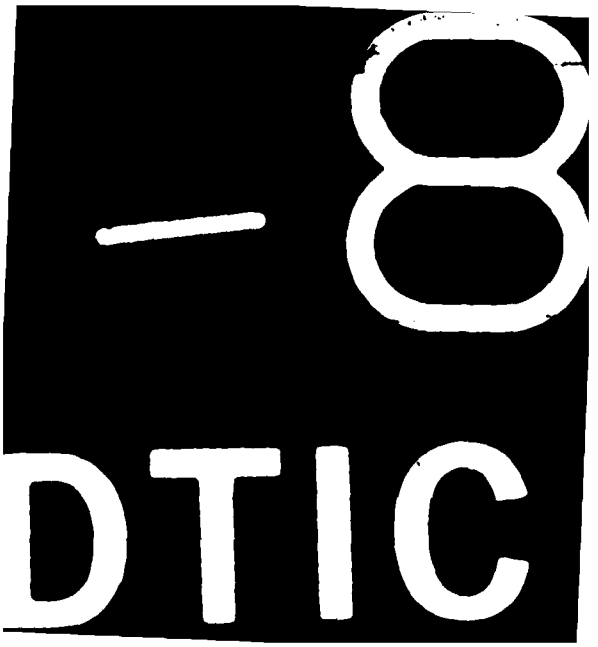
Related to the foregoing comment is the nature of faculty positions in OR and statistics in Europe. These faculty have no need for--indeed can't use--research funding to support themselves. However, small contracts are sometimes used to support associates (graduate students), buy lab equipment and computer time, and support travel. This tends to make support of European university research in OR and statistics relatively inexpensive compared with US requirements. Faculty generally have a situation like that of a judge, and all salary raises are "across the board"; promotions generally occur as a result of taking new positions. For example, in a seminar I gave at one distinguished Scandinavian university, I recall remarking that I had some interest in possibly using utility-theoretic evaluations of faculty performance. Several members of the audience were puzzled, they told me, about why anyone would try to evaluate faculty performance. As I pursued this, it became clear that their salaries and ranks were not related in any way to their professional performances.

Finally, let me reiterate a point I made in report R-2-83. European universities grew rapidly in the sixties and early seventies. They are currently declining somewhat in size, both because of economic difficulties and because of declines in the sizes of the student populations. As a result, there is virtually no recruitment of fresh young talent into university faculties. The result is a cohort of middle-aged faculty members, growing older together without turn-over and without the new ideas and new research interests that faculty recruitment brings. There is clearly a need for new mechanisms to encourage exchange among universities.

Recommendations

I hope the foregoing comments and those in R-2-83 support the following suggestions:

- Because of the language barrier, particular efforts should be made to monitor developments in France.
- There is a great volume of high quality research in OR and statistics in Europe. Specific developments that should be monitored include:
  1. Work on order statistics and "insurance mathematics" (UK, Germany, Belgium)
  2. Work on image processing (UK, France, Denmark, Norway).
  3. Work on statistical computing (UK)
  4. Work on correspondence analysis (France)
  5. Applications of Bayesian statistics (UK, Spain).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